Benefits of the IGS-BIPM cooperation in international time keeping

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IGS Workshop 2010

Newcastle upon Tyne (UK), 28 June – 2 July 2010

Outline

- Quicklook at the BIPM responsibilities and achievements
- The IGS-BIPM common interests and connexion
- Time transfer, an essential tool for international time keeping
- Use of the IGS products for time transfer in TAI
- Future

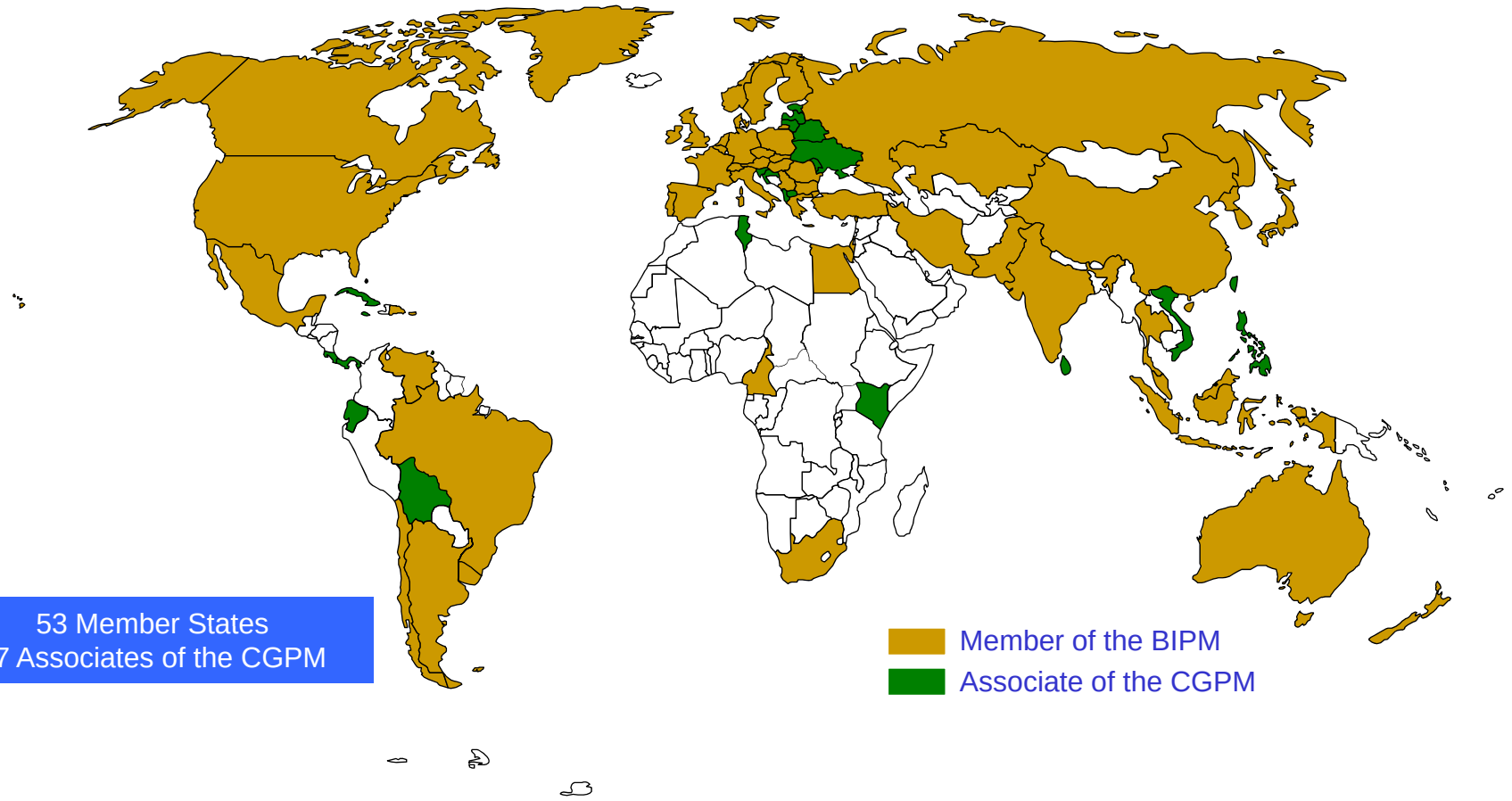
BUREAU INTERNATIONAL DES POIDS ET MESURES

It has headquarters near Paris, France. It is financed jointly by the Member States and Associates, and operates under the exclusive supervision of the CIPM.

Its mandate is to provide the basis for a single, coherent system of measurements throughout the world, traceable to the International System of Units (SI). This task takes many forms, from direct dissemination of units (as in the case of mass and time) to coordination through international comparisons of national measurement standards.

It has an international staff of over 70 and its status vis-à-vis the French Government is similar to that of other intergovernmental organizations.

BIPM Membership



53 Member States
27 Associates of the CGPM

CIPM Consultative Committees related to TFG work

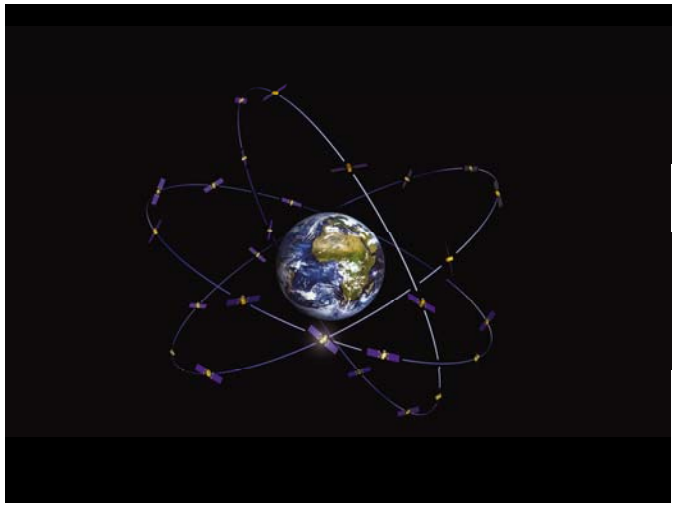
- ✓ CCTF (Consultative Committee for Time and Frequency)
  - ✓ Reference time scales TAI, UTC, TT
  - ✓ IUGG, IAU, URSI, ITU-R, IGS are members
- ✓ CCM (Consultative Committee for Mass and Related Quantities)
  - ✓ Working Group on Gravimetry
- ✓ CCU (Consultative Committee for Units)
  - ✓ IAU, CODATA, ISO are members

Time

✓Maintenance and dissemination of the international time scales TAI/UTC.

- ✓ Frequency stability is 0.4 x 10^{-15} @ 30-40 days
- ✓ Frequency accuracy is ~10^{-15}

✓Coordination of activities in time laboratories contributing to TAI/UTC.



✓Organization of the international network of time comparisons for TAI/UTC.

What do we need for TAI computation?

Time comparisons between real-time approximations to UTC: *UTC(k)* – *UTC(l)*

Section 1 of
BIPM Circular T

CIRCULAR T 268 ISSN 1143-1393
2010 MAY 07, 14h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES
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1 - Coordinated Universal Time UTC and its local realizations UTC(k). Computed values of [*UTC-UTC(k)*] and uncertainties valid for the period of this Circular. From 2009 January 1, 0h UTC, *TAI-UTC* = 34 s.

Date 2010 0h UTC	MAR 29	APR 3	APR 8	APR 13	APR 18	APR 23	APR 28	Uncertainty/ns		
MJD	55284	55289	55294	55299	55304	55309	55314	u_A	u_B	u
Laboratory *k*				[*UTC-UTC(k)*]/ns						
AOS (Borowiec)	-10.2	-8.3	-3.4	-2.2	-0.3	-0.2	-0.4	1.5	5.1	5.3
APL (Laurel)	-2.7	-1.8	-2.9	-2.8	-2.0	-2.7	-1.3	1.5	5.0	5.2
AUS (Sydney)	227.7	206.4	185.2	166.8	160.0	144.4	128.8	0.3	5.0	5.1
BEV (Wien)	55.5	47.0	45.7	35.9	26.3	27.2	30.1	1.5	3.1	3.5
BIM (Sofiya)	-6781.1	-6768.6	-6762.4	-6755.4	-6759.2	-6751.6	-6739.6	2.0	7.1	7.3
BIRM (Beijing)	-10173.8	-10212.2	-10255.0	-10298.3	-10346.1	-10378.6	-10414.1	2.0	20.0	20.1
BY (Minsk)	52.3	60.1	70.2	-24.7	-23.0	-21.2	-20.0	2.0	7.1	7.3
CAO (Cagliari)	-4097.4	-4117.2	-4128.8	-4141.4	-4141.0	-4158.1	-4193.5	1.5	7.0	7.2
CH (Bern)	-2.7	-4.5	-3.4	-3.6	-4.7	-6.1	-5.9	0.6	1.4	1.5
CNM (Queretaro)	-9.2	-10.3	-2.6	-1.1	7.4	15.5	19.5	2.5	5.1	5.7

Frequency comparisons: for primary frequency standards (steering TAI frequency)

Section 4 of *BIPM Circular T*
Generally obtained by differencing time comparisons

Standard	Period of Estimation		d	u_A	u_B	$u_{1/Lab}$	$u_{1/TAI}$	u	Ref(u_B)	u_B(Ref)	Note
PTB-CS1	55284	55314	-5.21	6.00	8.00	0.00	0.13	10.00	T148	8.	(1)
PTB-CS2	55284	55314	0.23	3.00	12.00	0.00	0.13	12.37	T148	12.	(1)
NIST-F1	55274	55299	6.38	0.37	0.31	0.19	0.46	0.69	T214	0.35	(2)
SYRTE-JPO	55284	55314	7.38	0.61	6.30	0.30	0.46	6.35	T160	6.30	(3)
SYRTE-FO1	55284	55314	4.84	0.30	0.40	0.11	0.46	0.69	T227	0.72	(4)
SYRTE-FO2	55284	55309	5.58	0.30	0.39	0.11	0.54	0.74	T227	0.65	(4)

Notes:
(1) Continuously operating as a clock participating to TAI
(2) Report 28 APR. 2010 by NIST
(3) Report 04 MAY. 2010 by LNE-SYRTE
(4) Report 05 MAY. 2010 by LNE-SYRTE

IGS-BIPM (1)

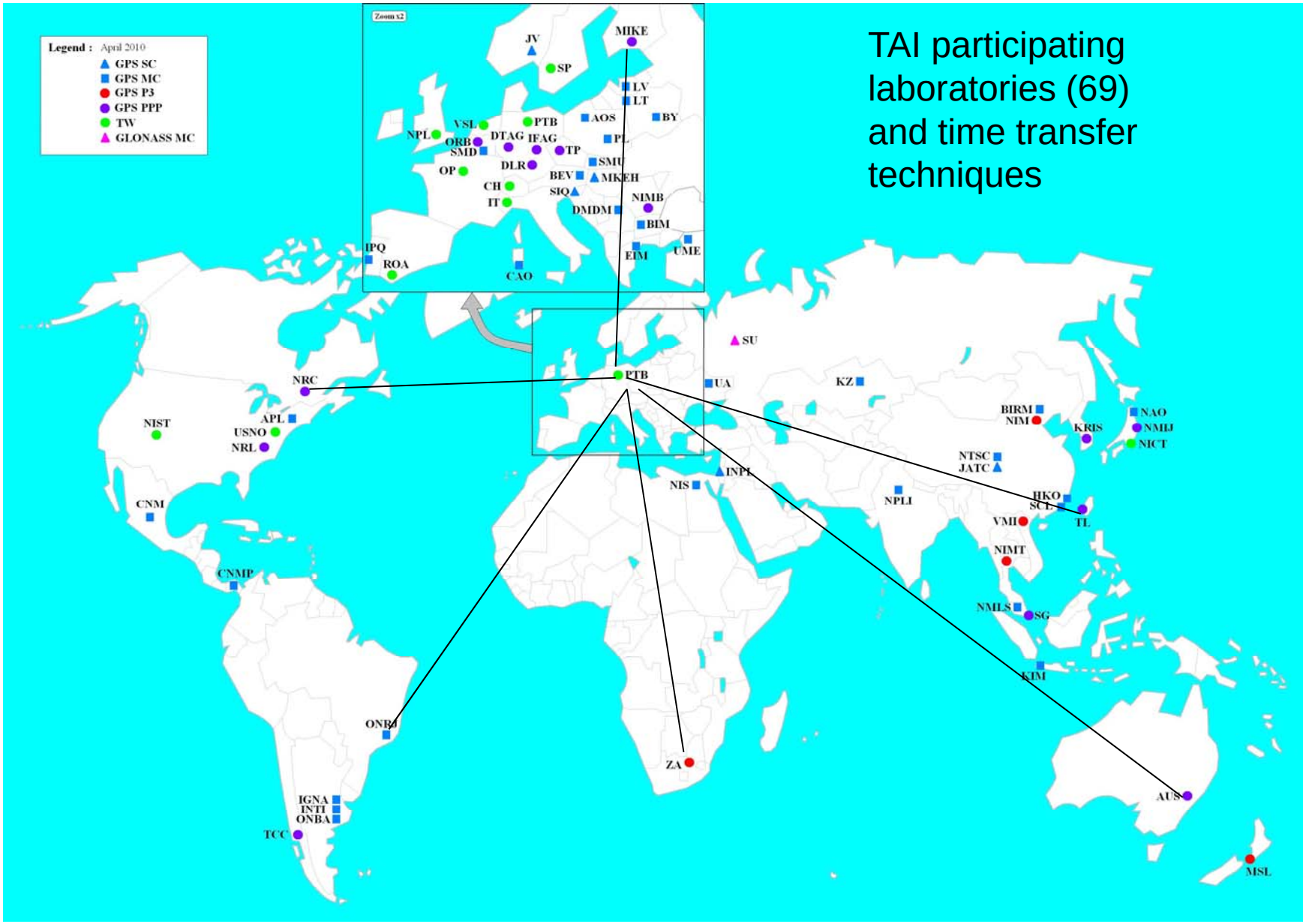
- Projects/actions of common interest
  - IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements (1999-2003)
  - IGS working group on clock products, with BIPM participation
  - IAG, GGOS
  - Actions within the International Committee for GNSS (ICG)
    - WG D, Task Forces on
      - Time references,
      - Geodetic references

IGS-BIPM (2)

- Official representation
  - BIPM is observer in the IGS Governing Board
  - IGS is a member of the Consultative Committee for Time and Frequency (CCTF)
- Fluid communication between individuals for technical issues

IGS-BIPM (3)

- **Production of TAI**
  - **GPS C/A Common views (in use until mid 2006)**
    IGS precise orbits
    IGS iono maps
  - **GPS P3 (since 08/2003)**
    IGS precise orbits
  - **GPS all-in-view (since 09/2006)**
    IGS precise orbits
    IGS iono maps
    IGS clock products
    IGST (instability 10^{-15} @ 1 day)
  - **GPS PPP (since 09/2009) – IGS/BIPM Pilot Project**
  - **GLONASS Common views (since 11/2009)**
    IGS-ESA precise orbits
    IGS iono maps


Legend : April 2010
GPS SC
GPS MC
GPS P3
GPS PPP
TW
GLONASS MC
Zoom x2
TAI participating laboratories (69) and time transfer techniques
JV
MIKE
SP
LV
LT
VSL
PTB
AOS
BY
NPL
ORB
DTAG
IFAG
PL
SMD
TP
SMU
DLR
OP
BEV
MKEH
CH
SIQ
NIMB
IT
DMDM
BIM
IPQ
EIM
UME
ROA
CAO
SU
NRC
PTB
UA
KZ
BIRM
NIM
NAO
NMIJ
KRIS
NICT
NIST
APL
USNO
NRL
NTSC
JATC
INPL
NIS
NPLI
HKO
SCL
TL
CNM
VMI
NIMT
CNMP
NMLS
SG
KIM
ONBO
ZA
AUS
IGNA
INTI
ONBA
TCC
MSL

Time transfer techniques in use

GNSS, mostly GPS

- Code measurements

  C/A (1.575 GHz, 1 Mchip/s)

  P1/2 (1.575/1.227 GHz, 10Mchip/s)

Achievable uncertainty: < ~ 1/few ns
Limited by
Multi-path reflections
Transmission delay in troposphere

- Phase + code measurements

  L1/2, P1/2 (1.575/1.227 GHz)

Achievable uncertainty: (few) 0.1 ns
Limited by
Phase ambiguity resolution
Various effects @ < 0.1 ns level

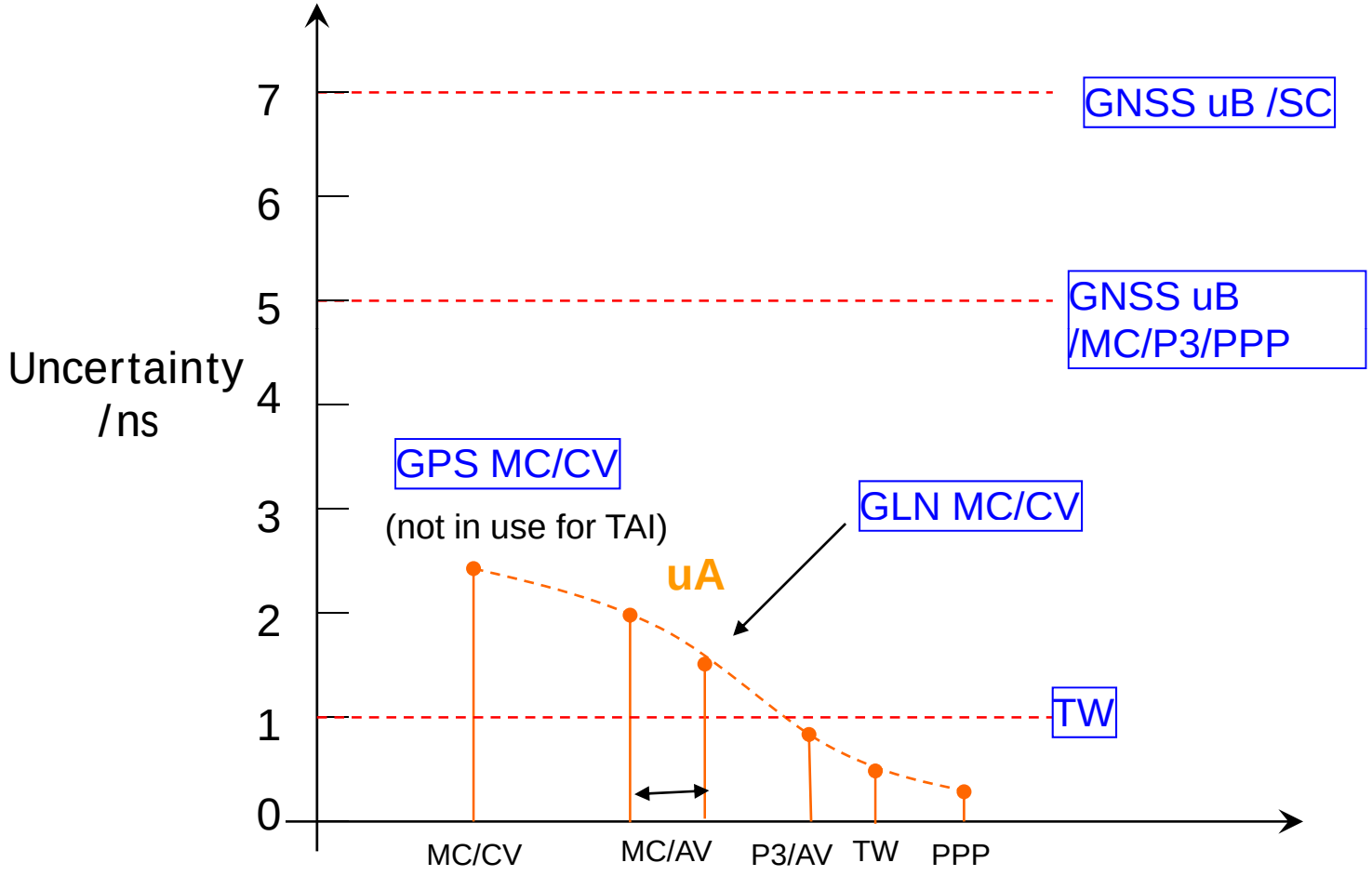
TW satellite time transfer

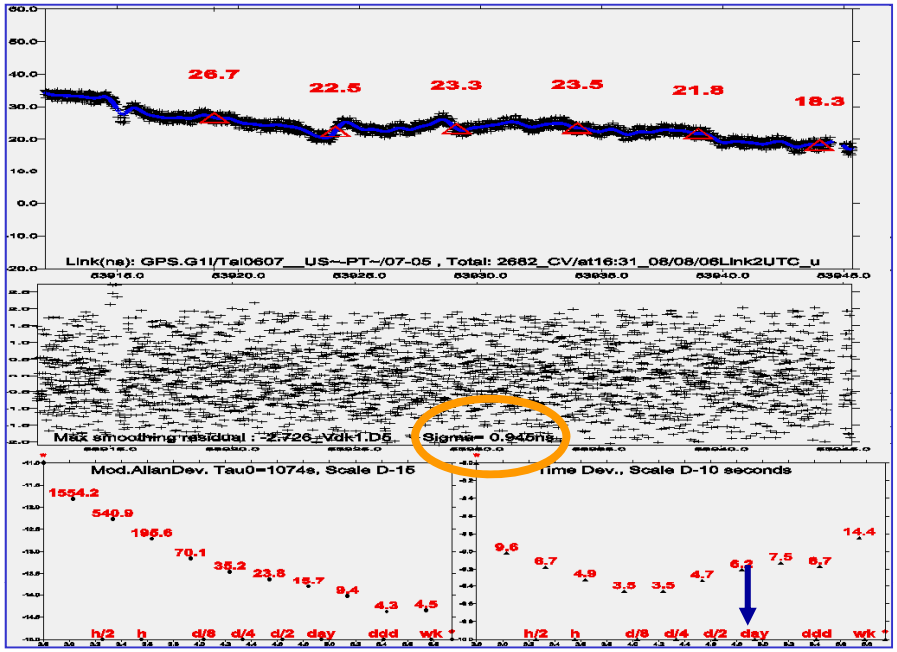
- Code measurements

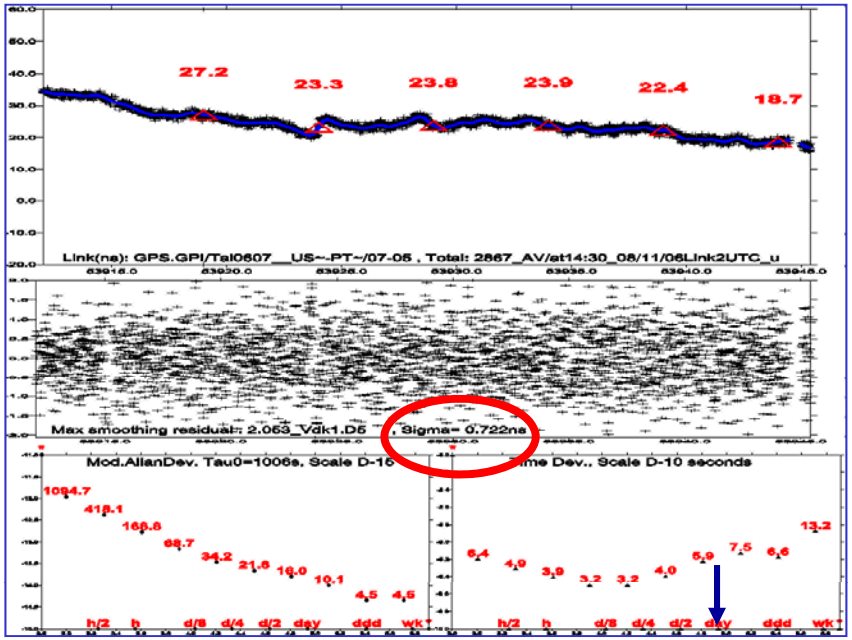
  Ku band (14 GHz, 1 Mchip/s))

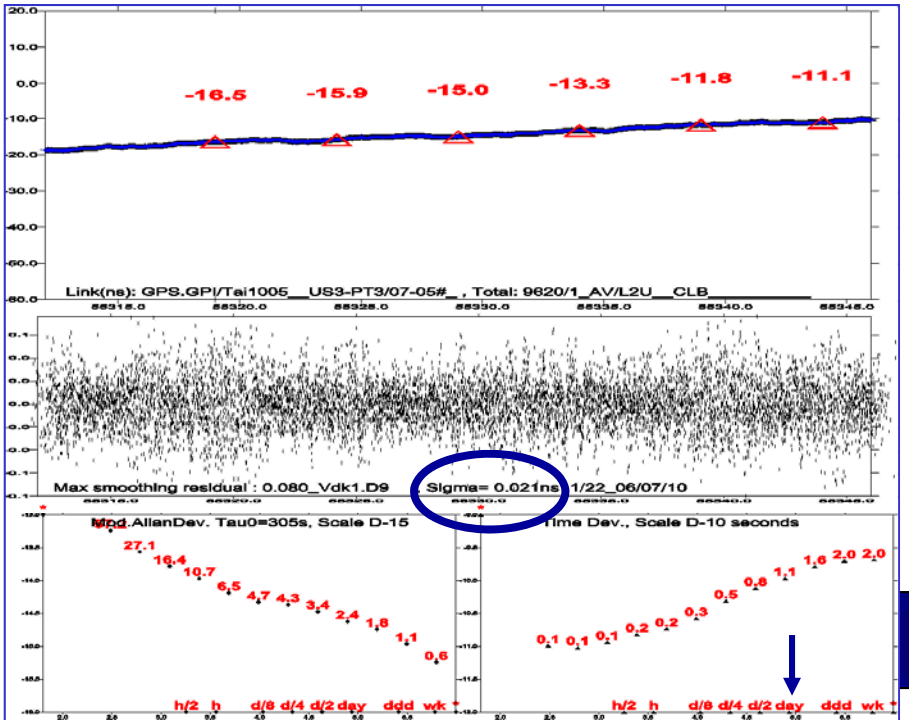
Achievable uncertainty: (few) 0.1 ns
Limited by
Effects on satellite equipment

Uncertainty of UTC time transfer (calibrated equipment only)









P3 CV

σ = 0.940 ns

P3 AV

σ = 0.722 ns

PPP

σ = 0.021 ns

What (more) shall we use tomorrow?

GNSS: GLONASS, Galileo

- Phase + code measurements

  New frequencies, new codes, more satellites

Significant improvement

Expected but not one order of magnitude

TW time transfer (dedicated payloads)

- Phase + Code measurements

Dedicated payloads should allow order of magnitudes improvements

Fiber links

Progressing so fast that it is difficult to forecast

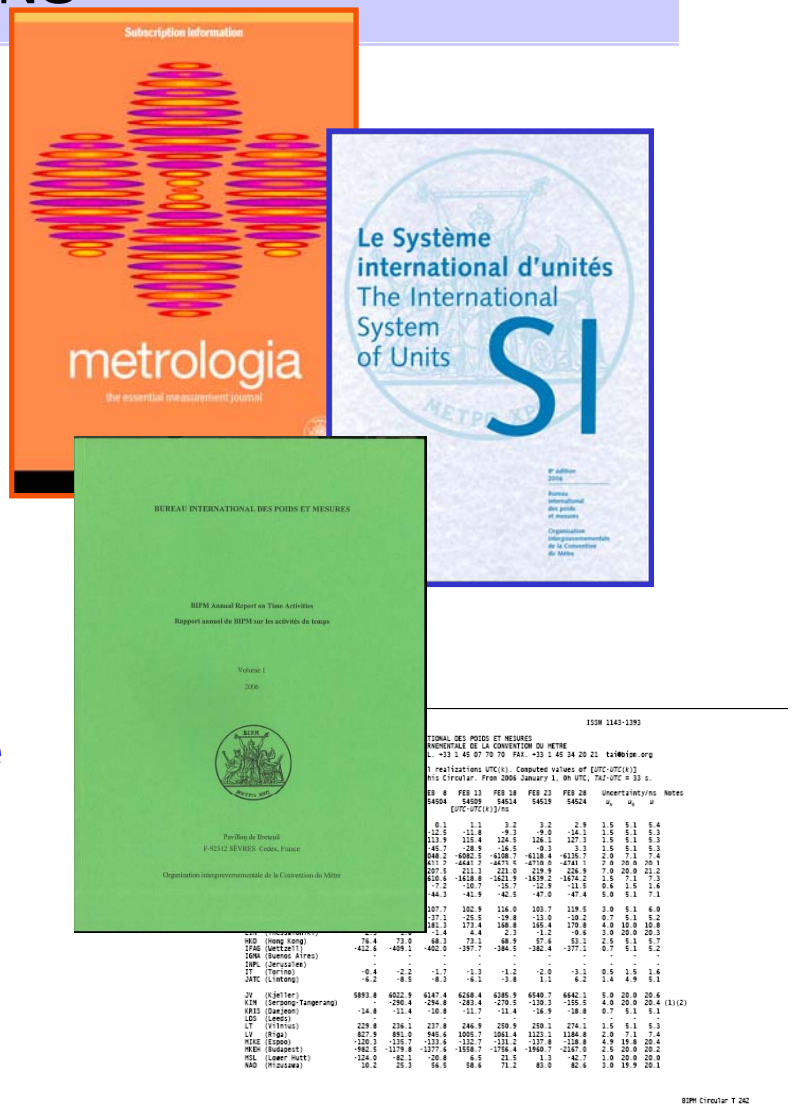
PUBLICATIONS

Metrologia **is an** international journal **dealing with the scientific aspects** of metrology.

The SI Brochure**.**

The BIPM **disseminates the time scales and gives traceability to UTC to participating laboratories through the monthly** *BIPM Circular T***.**

The *Annual report on Time Activities* **gives definitive results and complete information on TAI and UTC.**



www.bipm.org http://www.bipm.org/jsp/en/TimeFtp.jsp